

Personalized Intuitive Displays Enhance Pilot Performance

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ABSTRACT

*Modern cockpit instruments provide pilots with rich visual and auditory information about the aircraft and the mission. However, the information is not necessarily presented in the most effective way. For example, three-dimensional signals are presented on two-dimensional displays. Moreover, the information is often presented in an abstract manner, which consequently contributes to the pilot's cognitive workload. Although the cockpit environment is standardized to meet general regulations and efficiency, we hypothesize that there is still room for improvement since each pilot in principle perceives and processes information differently, based on individual constitution, experience and preferences. Although pilots are highly skilled in interpreting present-day displays, we believe that their performance may be further enhanced by intuitive displays, and also by the possibility to customize the displays to the individual needs. **Method:** We carried out a simulator study in the networked Mission Simulation Center at TNO. Seven (ex-)operational F-16 pilots evaluated the functionality of a set of new and intuitive displays in realistic scenario's. The displays involved a 3D audio system (manufactured by Terma), a tactile display, and a dual layer display. The TNO-built tactile display consisted of 60 small vibrating elements (tactors) arranged around the pilot's torso in five horizontal rings of twelve tactors at 30 deg intervals. The TNO dual layer display was implemented into the right Multi-Function Display by adding a transparent LCD*

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screen a few centimeters in front of the existing screen, so that information could be presented in two depth planes. The new displays were controlled by direct voice input. The pilots could choose which of the following functions were presented on either the 3D audio and the tactile display: Threat warning (derived from Radar Warning Receiver), wingman position (derived from Link-16), and the Minimum Recovery Altitude during weapon delivery. The Dual Layer display always presented an overview of the current situation. After two practice trials, pilots tested the displays in three operational simulator scenarios of 20-30 minutes. Scenarios were flown in a two-ship with the wingman flying in another F-16 simulator that was networked with the test pilot's F-16 simulator. All three scenarios had the same level of complexity, and contained several air and ground threats that had to be negotiated before a final air-to-ground delivery. **Conclusions:** The pilots were highly enthusiastic about both the new displays and the possibility to adjust the settings to their personal preference. They differed in the way they used the new displays. Some of them preferred one setting systematically throughout the whole scenario, e.g. air threats presented on the tactile display. Other pilots changed more frequently between different functions, depending on the phase of the scenario. Results based on self ratings and expert pilot observer data indicated that pilot performance may be improved by using more intuitive displays and a customized cockpit. Further research will include improving the intuitiveness and customization of the cockpit by use of Smart Systems and Artificial Intelligence.

1.0 INTRODUCTION

Modern fighter aircraft are equipped with highly sophisticated cockpits. Their design is the result of years of development and optimization. The cockpit informs the pilot about the status of the aircraft and the mission, and allows for the control over the many aircraft systems. Pilots are trained to make effective use of this. Because they all operate the same cockpit, all pilots are trained in the same way. In general, there is little about a cockpit that the pilot can adjust to his own needs. This basically means that the pilot must adapt to the standard. The question addressed here is whether a standard cockpit really is the most effective environment for the non-standard pilot. People differ in their information processing: for example, some are tuned to visual signals, others pick up auditory information more easily.

Within the RNLAf/TNO Research Program *Pilot Factors*, the current study was defined to investigate whether we can improve the performance of highly skilled pilots by 1) offering them cockpit information in an intuitive way by multiple sensory modalities, and 2) allowing them to customize the displays to their personal needs. For this purpose, one of the four F-16 cockpits in the Mission Simulation Center (MSC) was equipped with multi-modal interfaces which can be adjusted by the individual pilot: A tactile torso display; a 3D audio head set; and a dual layer display. These new interfaces are additional to existing instruments. They do not add information, but offer an extra or alternative channel to display certain parameters. The new displays are designed to present information in an intuitive way. For example, with the 3D audio interface one can hear a sound coming from a certain direction. In addition to these new displays, a speech interface allowed pilots to control the cockpit by means of direct voice inputs.

The long term goal of the research program is to have the cockpit adapt automatically to the pilot. The next step in that direction will be to predefine the display settings that a single pilot prefers for different situations. The ultimate step will be to include artificial intelligence that monitors the development of the scenario and the pilot's capacity, and adjusts the cockpit accordingly.

2.0 METHODS

2.1 Mission Simulation Centre

The TNO/RNLAF Mission Simulation Centre (MSC) contains four networked F-16 simulators. Three fixed-base simulators feature original F-16 cockpits, and differ in the type of visual Out-The-Window display (Dome, Cylinder, Helmet Mounted Display). Cockpit instruments, throttle and stick are replaced by simulated replicas. The fourth simulator is built in the motion-base DESDEMONA facility. In the current study, only two of the four cockpits were used: the cylinder and the dome (Figure 1). The multi-modal interfaces have been implemented in the dome-simulator, designated Multi-Modal Suite (MMS).

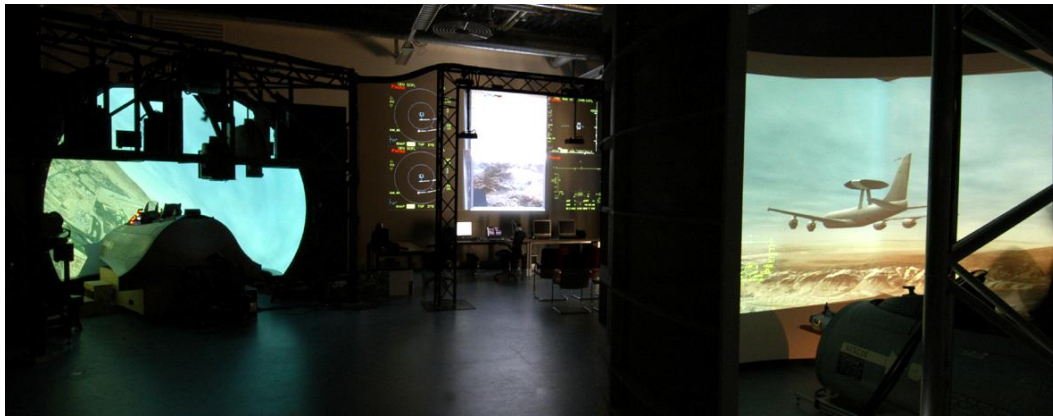


Figure 1: Two F-16 simulators in the Mission Simulation Centre. The dome cockpit (left) was operated by the subject-pilot. The cylinder simulator (right) was operated by the wingman.

The simulators used the advanced F-16 flight model by Bihrlé Applied Research (DSix version 1.95). Scenarios were developed in the mission environment of Simigon Airbook (version 5.2). The interface with the MMS was built by TNO using C++ plug-ins. Out-the-window imagery was computed by Evans & Sutherland (EPX50) image generator, and projected on three (cylinder) and eight (Barco SEER8 minidome) Barco projectors, respectively.

2.1.1 Multi-Modal Suite (MMS)

The cockpit of the Multi-Modal Suite (MMS) was equipped with four new interfaces: Voice Interface, Tactile Display, 3D audio display, and Dual Layer Display.

2.2.2 Voice interface

The voice interface consisted of software modules that use speech as an input or generate speech or audio as an output. The Direct Voice Input (DVI) module embeds an Automatic Speech Recognizer (ASR), the Direct Voice Output (DVO) module is based on a Text-To-Speech (TTS) system, the Audio Dispatching Module (ADM) is used for sound generation. All modules operate independently but are controlled by a dialogue manager by means of a network protocol. The DVI, DVO, and ADM modules are described below.

2.2.2.1 Direct Voice Input (DVI)

For voice input we implemented Loquendo ASR version 6.7. As voice recognition is not guaranteed 100% correct, voice input was restricted to non-critical actions/commands. Feedback on voice commands was either given in the form of a voice message (speech synthesis), or by displaying on the existing displays (e.g. UFC, MFD, HUD). For example, the former was done with (de-) activation of a display, whereas the latter was done with the setting of frequencies.

The voice commands were designed in such a way that they were intuitive, consistent, as short as possible and acoustically distinct (e.g. we use “on”/“switch off” instead of “on”/“off”). The recognition grammar was designed in an iterative process in which an expert user was used to provide feedback. Also, the recognition accuracies of various versions of the grammar have been tested. Recognition accuracy was improved by modelling pronunciation variation (adapting the acoustic models and optimizing the word pronunciations) and by training speaker-dependent acoustic models, resulting in word accuracies of 98.5% (tested on an independent test set of 48 representative commands). Table 1 shows the voice commands used for the different functions used in this study. The rows are grouped around each of the four interfaces, as indicated in the first column: Voice, Dual layer display, Tactile display, and 3D audio display. Within each interface the available functions are indicated by the next two columns (column 2-3). Columns 2-4 together compose the voice command to activate, respectively deactivate the corresponding functionality. For example, the voice command to activate the function of “active wingman” on the tactile display is “Body active wingman on”. In this study, each display could only present one function at the same time.

Function	Voice command		Description	
Voice Commands	Comm 1	Preset	<1-20>	
	Comm 2	Preset	<1-20>	
	IFF	Mode	1	On / Switch Off / <00-73>
			2	On / Switch Off / <0000-7777>
			3	On / Switch Off / <0000-7777>
			4	On / Switch Off / Alpha / Bravo
			Charly	On / Switch Off
		All modes	On / Switch Off	
	Tacan	Channel	<1-126>	X-ray / Yankee
		Mode	Switch Off / Receive (only) / Transmit Receive / Air-to-air	
	ALOW	AGL	<0-50.000>	
		MSL		
	Bingo	<0-10.000>		
		<1-29>		
	Bullseye	On / Switch Off		
Steerpoint	<1-127>			
Input / Store	Release	<0-50.000>		
	Min Release			
	Hard deck		note: Hard deck is connected to Advisory Altitude	
Output / Say	Altitudes	note: Repeats Release, Min Release and Hard deck altitudes		
Undo				
Dual Layer Display	Bottom Layer	Less relevant info	All exept what is displayed on the top layer	
	Top Layer	Most relevant info	Radar contacts and related symbology Link-16 symbology	
Tactile Display	Body	Passive wingman	On / Switch Off	Direction towards wingman (space oriented) continious
		Active wingman		Warning when wingman is close
		Ground threat		Direction towards wingman (space oriented) on radio call
		Air threat		Direction towards ground threat (ground oriented)
		Advisory altitude		Direction towards air threat (ground oriented)
		AMRAAM		Warning when reaching hard deck from above
				Warning when missile goes active
				All Body function off
(3-D) Audio Display	Audio	Passive wingman	On / Switch Off	Direction towards wingman (space oriented) continious
		Active wingman		Warning when wingman is close
		Ground threat		Radio call wingman from wingman direction (space oriented)
		Air threat		Direction towards ground threat (ground oriented)
		Advisory altitude		Direction towards air threat (ground oriented)
		AMRAAM		Warning when reaching hard deck from above
				Warning when missile goes active
				All Audio functions off

Table 1: Voice commands and corresponding functions.

2.2.2.2 Direct Voice Output (DVO)

Voice output was used to give feedback on the voice input when speech is more appropriate than audio signal, or when visual feedback was not possible. This was for instance the case for switching on/off new interfaces (e.g. the tactile interface). For voice output, we used Nuance RealSpeak Solo 4.0, USA male voice (Tom) Text-to-Speech software. Pronunciation and speech tempo was tuned manually.

2.2.3 Tactile display

The tactile display consisted of a vest with 60 vibrating elements, or so-called “tactors”, worn around the pilot’s torso, as tested before in a fighter environment [1]. The vest is shown in Figure 3 (left). The tactors were made of pager motors embedded in small plastic boxes (Figure 3, right). The activation of the tactors was computer controlled. When active, tactors vibrated at a fixed frequency of 150Hz. The vibration amplitude was not adjustable. All tactors were arranged in five rings and 12 columns. Hence, signals could be presented in 12 segments of 30 deg in five horizontal planes. In the sections below, the five horizontal rings will be numbered 1 through 5, starting at the top.



Figure 3: TNO Tactile Torso Display (left) and inside view of tactor (right).

As shown in Table 1, the pilot could select one of six different functions on the tactile display:

2.2.3.1. *Passive wingman (PW)*

In this mode, the tactile display continuously indicated the 3D direction in which the wingman is located relative to the own ship. Obviously, the limited spatial resolution of the tactor configuration did not allow for a 1:1 mapping of all relative directions. For that reason, the horizontal direction (azimuth angle) was projected onto the tactor being closest. The vertical indication was coded in five segments. The middle tactor ring (3) was used when the vertical position of the wingman was within -15 and +15 deg relative to the own level. Angles between +15 and +45 deg (-15 and -45 deg) were projected on tactor ring 2 (respectively 4). Angles between +45 and +90 (-45 and -90) were projected on the upper (1) or lower tactor ring (5). The direction of the wingman was corrected for attitude changes of the own ship, so that the wingman was always presented in egocentric coordinates. Tactors were activated with a 200ms on/200ms off rhythm.

2.2.3.2 Active wingman (AW)

The relative position of the wingman was similar as in the passive wingman mode, but only when the wingman was communicating (this mode was linked to a push-to-talk button of the wingman).

2.2.3.3. Ground threat (GT)

The azimuth angle of ground threat was indicated on the 12 tactors of ring 5. In inverted flight (aircraft attitude $> 90^\circ$) the direction was mirrored to ring 1, so as to maintain a rough egocentric coordinate system. A maximum of two threats could be presented at the same time. The duty cycle for both stimuli was 1400ms. The tactor representing the first threat was activated three times at the beginning of a duty cycle with 100ms on/100ms off. The second threat was indicated in anti-phase with the first threat signal (Figure 4).

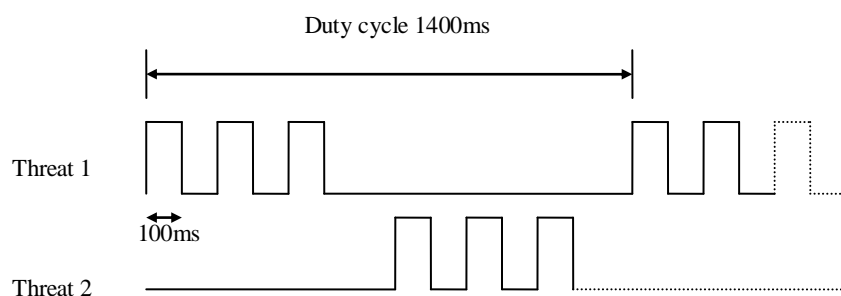


Figure 4: Activation pattern of two simultaneous tactile warnings.

2.2.3.4. Air threat (AT)

In the air threat mode, the tactile display presented the direction of a maximum of two enemy aircraft with the same activation pattern as the ground threat mode (Figure 4). However, where the ground threat mode only indicated the 2D horizontal direction, the air threat mode also presented the 3D vertical direction similar to the wingman mode. The activation pattern was 100ms on/100ms off.

2.2.3.5. Advisory Altitude (AA)

This function was used in air-to-ground situations, and comprised two signals. The first signal was presented on three consecutive tactors mid-front ring 2, which alerted the pilot about approaching the minimum release altitude and was a function of the dive angle. The signal consisted of one burst of four activations with 200ms on/200ms off. The second signal alerted the pilot about crossing hard deck. Because of its importance, this signal was made extra strong: During 3 seconds, all 12 tactors of ring 4 were activated 200ms on/200ms off.

2.2.3.6. AMRAAM

In this mode, a single tactor was activated briefly when the AMRAAM became active.

2.2.4 3D audio interface

The same functions described for the tactile display could be presented on the Terma 3D audio system (Denmark). Head tracking was performed by a Polhemus Fastrak RevE headtracker. For all pilots we used the default Head-Related Transfer Function (HRTF's), as was provided with the system.

2.2.5 Dual Layer display

The TNO “Dual-Layer Display” (DLD) provides one extra depth layer over standard (flat) displays, increasing the information capacity of the display (Kooi, in print). The DLD consists of two orthogonally placed LCD displays, which are viewed by the observer via a semi transparent mirror placed with an angle of 45 deg. In this way information of one of the displays is presented in the foreground relative to the other display which is seen in the background. The distance was set at 12mm, which is the maximum value for the prototype DLD used here (with LCD displays with a diameter of 6.4 inch). In the MMS the DLD was built in as the right Multi Functional Display (MFD) for presenting information of the radar and Link-16 (Figure 5). At the time of the study the DLD could not be adjusted real-time, and throughout the experiment it presented an overview of the situation. Because pilots could not adjust the DLD, we will not discuss the results of the DLD.

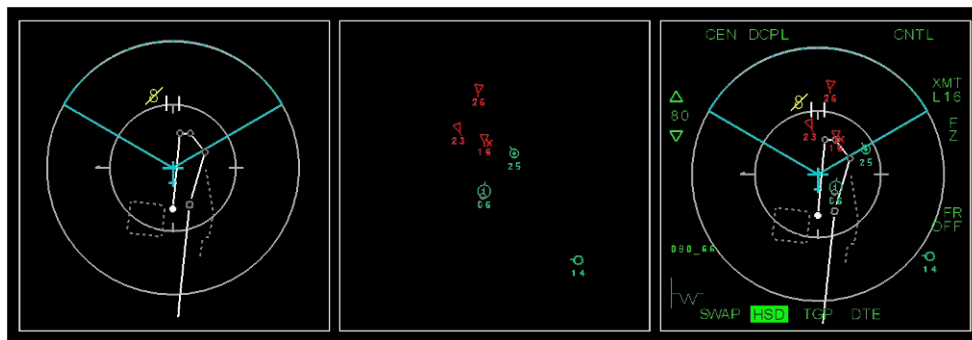


Figure 5: Dual Layer Display implemented in the MFD. The left and right panel shows the rear and front display, respectively, and the right panel shows the two layers on top of each other.

2.3 Operational scenarios

2.3.1 Scenario description

The operational scenarios were as close as possible to real training scenarios. The mission was to fly as a 2-ship through a defended area and attack a ground target. The pilots received an “air picture” via the Link-16 network but did not receive any fighter control. Due to limitations of the MSC and the MMS, the scenarios were divided into three main phases: the Ground-to-Air phase, the Air-to-Air phase and the Air-to-Ground phase. Figure 6 gives a schematic set-up of an Air-to-Air phase in one of the scenarios. During the Ground-to-Air phase the formation encountered two SAM-sites, during the Air-to-Air phase up-to six hostile aircraft before they reached the target area. During the Air-to-Ground phase the target attack took place. In total there were six scenarios, which had the same ingredients but different initial conditions. The scenarios differed by changing the presentation of hostile aircraft. Every presentation forced the subject pilot to make a different decisions. The scenarios had the same difficulty level. This way, each pilot carried out six different, but comparable scenarios.

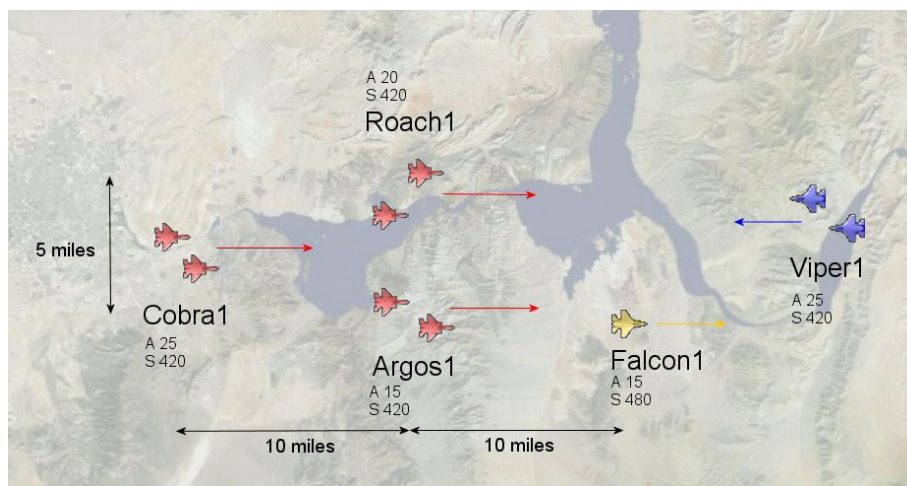


Figure 6: Example of Air-to-Air phase, showing three hostile groups and one friendly. Viper1 is the own ship formation.

2.3.2 Scenario difficulty level

The limitations of the MSC limited the difficulty level of the scenario's. Normally the above mentioned phases could happen at the same time. The MMS, in its current version, did not allow multiple threat categories to be displayed at the same time. For this reason the threat phases were separated otherwise the pilots would have to make an unrealistic choice based on expected threat priority. The impact on the experiment would be unpredictable. Also the computer generated threats were not "smart" enough to oppose a realistic difficulty level. For this reason the pilots had a limited weapon load against multiple threats which increased the difficulty level. The expert pilot acting as wingman also increased the difficulty level by forcing the subject pilot to divide his attention between threat and formation integrity. Although the scenario difficulty was acceptable for the experiment they were expected to be insufficient to increase the pilot workload to a level which would allow produce noticeable performance differences.

2.4 Procedure

The study consisted of three sessions, separated over three different days. The first session was to familiarize the pilots with the MMS. The control of the various displays and their functionality was explained and practiced. In the second session, the pilots were given the opportunity to determine their personal preferences. In the third and final session, the MMS was tested in the operational scenarios, and compared with the standard F-16 cockpit. In the latter session the actual experiment took place. Pilots carried out the six operational scenarios described above. A block of three of the scenarios was flown with the use of the MMS. The subject pilot would start with his personal settings as determined in the second session, although he was free to deviate from this whenever he felt the need. A second block of three scenarios was flown in the traditional cockpit. The same order of six scenarios was used for all pilots, because all scenarios were comparable (containing the same phases and type of events). The order of the two blocks (with and without MMS) was counterbalanced between pilots. The subject pilot flew as formation lead while the expert pilot flew as wingman.

2.5 Measurements

Directly after each scenario, a 10 minute debriefing was performed by the expert pilot, asking the subject pilot to recall:

- The flow or “spaghetti” (i.e., course of most important moments, actions and results in order of occurrence)
- Situation awareness related to threat and wingman
- Comments on the displays and functionalities

The MSC operator and expert pilot noted all voice inputs made by the pilot, so as to examine the exact use of the MMS during each phase of the scenario. In addition, the pilots’ opinion was collected using two different questionnaires:

- Questionnaire 1 – Functionality of the MMS in the operational test scenarios
- Questionnaire 2 – Expected usefulness of MMS in actual operations

Questionnaire 1 contained a total of 44 statements about the ergonomics and functionality of the MMS interfaces, which could be answered on a seven-point scale (ranging from “totally disagree” to “totally agree”). There were 12 statements about the tactile display, and the same 12 statements about the 3D audio display. Five statements concerned the DLD as well as the Voice Interface, and ten more statements dealt with the MMS concept in general. The questionnaire was filled out at the end of third (experimental) session at the end of the study.

Questionnaire 2 was used to determine how the pilots’ expectations and opinion about the MMS developed throughout the study. It was administered before the start of the study, and subsequently after each of the three sessions. Ratings were given on a five-point scale (ranging from “not at all useful” to “extremely useful”). A five-point scale was chosen instead of the seven-point scale, to make the answers better comparable to the logging system used by the expert pilot.

2.5.3 Subject pilots

Seven RNLAf F-16 pilots participated as subject in this experiment. Two of them were very experienced retired F-16 pilots which have been out of service for less than two years. Five pilots still operationally fly within the RNLAf. The experience of all pilots ranged from 1000 to 2300 flying hours on the F-16 with an operational status ranging from 2-ship lead, force-lead to weapons instructor and test pilot.

2.5.4 Expert pilot

The expert pilot was a retired RNLAf F-16 experimental test pilot and weapons instructor. He flew over 2000 hours F-16. During the experiment he observed the subject pilots and flew as wingman.

3.0 RESULTS

3.2.1 Pilot performance

All subject pilots noticed that the MMS increased their threat awareness, especially for ground threats. Four pilots used the MMS to improve their wingman awareness. All pilots used the MMS for altitude awareness helping them to prevent crossing the “hard deck”. The MMS provided additional and intuitive information. One pilot said he felt “more at rest” as the MMS lowered his task saturation. The increased ground threat awareness gave another pilot a “warm fuzzy feeling” as he knew more about the threat positions and found it easier to find missile launches. All pilots and the expert pilot subjectively noticed a

difference in performance between flying with and without the MMS. The increased awareness level with the MMS allowed the pilots to make more efficient decisions and decreased their workload. Due to the limited difficulty of the scenarios the subject pilots were not pushed to their performance limits. All subject pilots, and the expert pilot, expected that the effect of the increased awareness level with the MMS would become more prominent when flying more difficult scenarios.

3.2.2 Operational use of MMS

The operational use of the tactile and 3-D audio display is shown in Figure 7 for each individual pilot.

The data clearly shows similarities and differences in preferred uses of the MMS between subject pilots. While five pilots used the tactile and audio displays to increase their threat and wingman awareness, two pilots only used the displays for threat awareness. Both preferred using the Link-16 data for their wingman awareness. Most pilots switched between functions on their displays between phases, but some minimised switching and constantly kept the same function active as a way to avoid confusion about the signal. By minimising switching they also reduced the workload to manage the MMS and prevent forgetting to switch to the intended function, which actually happened several times.

Pilot	Display	Ground-Air phase	Air-Air phase	Air-Ground phase
1	Tactile	GT	AT	AA
	Audio	GT	PW AT PW AT PW AT	AA
2	Tactile	GT	PW	AA
	Audio	AT	AA	AA
3	Tactile	GT	AA	AA
	Audio	AW	AT	AA
4	Tactile	GT	AT	AA
	Audio	AT	OFF	AA
5	Tactile	GT	AT	AA
	Audio	AW	AA	AA
6	Tactile	GT	AA	AA
	Audio	AW	AA	AA
7	Tactile	GT	AT	AA
	Audio	GT	AT	AA

Figure 7: Chart showing the selected functions on tactile and 3D audio display in different phases of the mission. "OFF" means display OFF. GT=Ground Threat (green); AT= Air Threat (blue); PW=Passive Wingman (orange); AW=Active Wingman (yellow); AA=Advisory Altitude (red).

3.2.2.1 Tactile display use

All pilots preferred tactile ground threat indications during the Ground-Air phase which allowed them to react to the threat without abandoning other tasks. Three pilots preferred tactile air threat indications during the Air-Air phase while two pilots preferred to continuously have tactile ground threat displayed during this phase. Both pilots wished to maintain clarity in the warnings on the different displays. Two pilots maintained clarity between the displays by using the tactile display for the expected threat (ground or air) while using the 3-D audio display for wingman awareness. Only one pilot used the tactile display for wingman awareness during the Air-Air phase. Four pilots used the tactile display for altitude awareness during the Air-Ground phase while the others maintained tactile threat or wingman indications during this phase. In general the tactile display was mainly used for threat indications.

As shown in Figure 8, pilots found that two practice trials offered sufficient practice with the tactile display (question 1), indicating the intuitive nature of the display. All pilots were positive about the clarity of tactile signals, and all but pilot 3 found them easy to interpret (questions 3-5), especially with respect to the stimulus direction (question 7). Not all pilots rated the comfort of the tactile display as high (question 2). The prototype tactors are encased in a plastic box, which presses against the pilots' back. The

resolution of the tactile display was judged reasonable, but not perfect (question 6). Only two pilots could easily discriminate different tactile signals (questions 9 and 10).

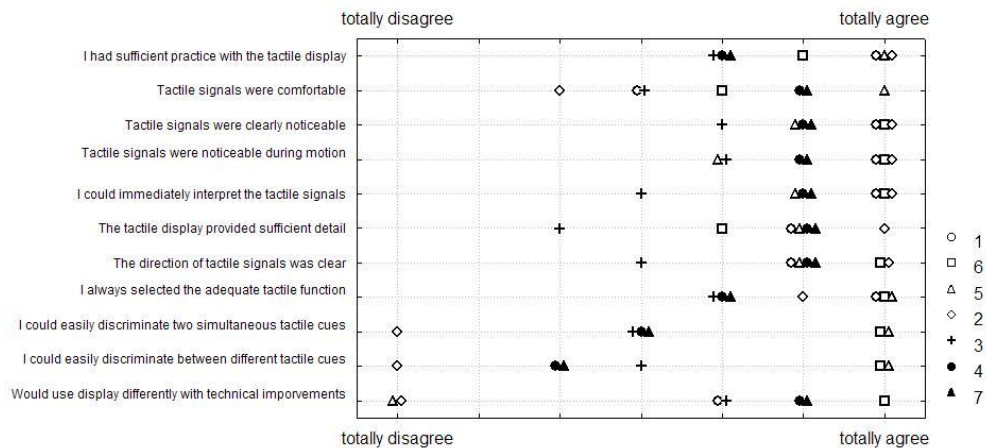


Figure 8: Individual ratings of tactile display.

3.2.2.2 Audio display use

Three pilots used 3-D audio for wingman awareness during the Ground-Air phase while two pilots used it for ground threat and two for air threat. Four pilots used 3-D audio for air threat awareness during the Air-Air phase while two use it for wingman awareness. One pilot did not use 3-D audio at all during the Air-Air phase. He thought 3-D audio was not that effective. Five pilots used the extra audio warning for altitude awareness during the Air-Ground phase while two pilots used 3-D audio for wingman awareness during this phase. In general, the audio display was used by half of the pilots for threat awareness while the others preferred wingman awareness.

Figure 9 shows the results for the 3D audio display. Not all pilots found the signals entirely comfortable. Compared to the tactile display, 3D audio signals seemed to be more difficult to detect and interpret (questions 3-5). According to question 6, the resolution of the audio display was not perfect. Since we used one generic transfer function to compute the simulated direction of audio signals, this can be improved by using customized transfer functions. Simultaneously presented signals in the air threat mode were not discriminated very well (question 9). Different signals for different function, however, could be discriminated better (question 10).

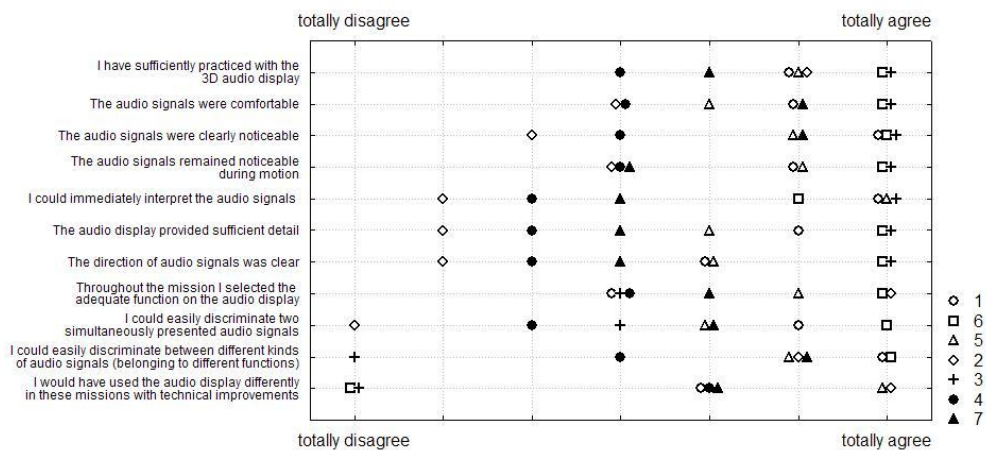


Figure 9: Individual ratings of 3D audio display.

3.2.3.5 Judgments on MMS concept

Figure 10 shows the pilots' judgments of the MMS concept. Clearly, the ratings are quite scattered. All pilots were mildly to wildly positive about the statement that the MMS increased the mission effectiveness (question 1). Two out of seven pilots indicated to be distracted by the MMS displays (question 2). Four pilots felt that the MMS helped to lower workload; three others disagreed (question 3). Five of them were able to fly more heads up with the MMS (question 4). Most pilots were able to scan the displays and found them complementary (questions 5, 6 and 7). Without feedback on the display status it was difficult to remember which MMS function was active (question 8). Finally, the majority of pilots was content with their individual settings for operational conditions (questions 9 and 10).

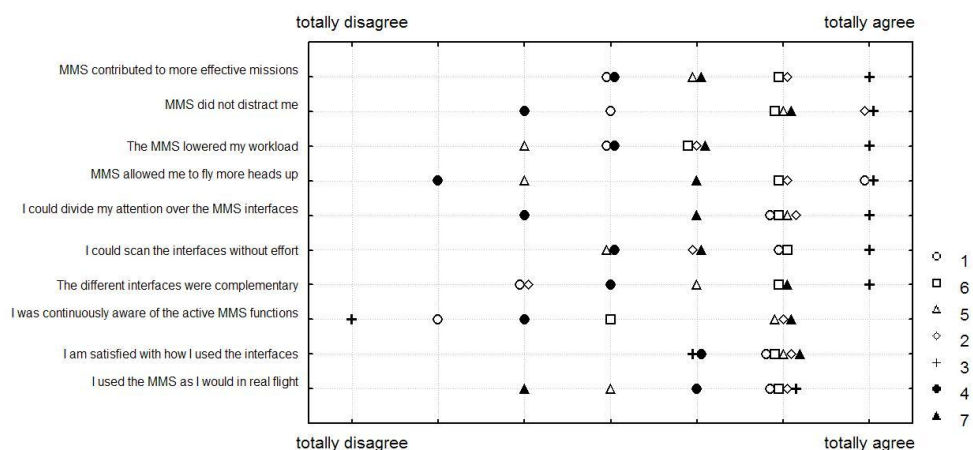


Figure 10: Ratings on MMS concept.

4.0 CONCLUSIONS

The two objectives of this study were to show that: 1) Pilots use the possibility to personalize the cockpit displays to their own needs; and 2) The MMS displays have added value in operational scenarios. Based on the expert evaluation and the questionnaires we conclude that the study succeeded in both objectives. All pilots were very positive about the Smartcard concept and the intuitive MMS displays. During the final experiment with operational scenarios they all used MMS features, although they were free to decide not to use any of them and just use the traditional cockpit.

In line with the first main objective, pilots clearly differed in their personal preference of MMS settings. This shows that personalization of the cockpit (interfaces) is desired and works. Concerning the second objective, most pilots adjusted their setting for each phase in the mission, so as to optimize the support from the MMS and increase their operational efficiency (although some pilots minimized switching between functions to avoid confusion about the setting, or to prevent forgetting to switch to the intended function). All subject pilots agreed that the Smartcard concept increased their awareness, and as such offers added value in operational conditions.

The study revealed many other useful observations, and pilot comments. As we had expected, there were many suggestions to make necessary technical improvements of the MMS. Most important, pilots were missing adequate feedback about the status of the MMS displays, and although they indicated to have sufficient practice, they had some difficulty in managing the MMS. The MMS displays themselves can also be improved. For example, voice input (recognition) was not error free to the extent that pilots would rely on it in actual flight. Tactile signals were not yet optimized for the different functions, especially where two or more signals are presented simultaneously. Not all pilots were satisfied about the directional hearing in the 3-D audio system, which may be due to the fact that we used a generic Head-Related Transfer Function.

Based on these findings, we will further develop the MMS so that multiple functions can be displayed on the same display at the same time. This allows for presenting high-priority signals (e.g. threat) on top of another signal (e.g. wingman). Because this feature was not available in this study, we had to design the operational scenarios into clearly separated phases. With this feature, events can be presented in a more random way, increasing the complexity of the scenario. Ground and air threat change quickly, and be a factor at the same time and during the ground attack. This could increase the number of required switches between functions as priorities change quickly. In addition, we will upgrade the content and artificial intelligence of the MMS mission environment so as to include more smart components. This will allow for even more demanding scenarios. Finally, automatic or “smart” switching functions will be implemented to help the pilot to reduce workload managing the MMS and prevent forgetting to switch. Pilots will be able to program the MMS to meet their personal preference. This “smartcard” would control the MMS to present the pilots with the information most suited for the phase of the mission. Figure 7 illustrates the idea of this smartcard, being a personal setting depending for different phases of the mission. An automatic system should be able to detect each important phase of the mission, and the smart system should be able to predict the most suitable setting.

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REFERENCES

- [1] Eriksson L., Van Erp JBF, Carlander O., Levin B., van Veen H.A.H.C., and Veltman J.E. (2006) Vibrotactile and visual threat cueing with high g threat intercept in dynamic flight simulation. In: Proceedings of the Human factors and ergonomics society, 50th annual meeting 2006. Santa Monica: Human Factors and Ergonomics Society pp. 1547 – 1551
- [2] Kooi F.L. (in print) A display with two depth layers: Attentional segregation and declutter. In: Attention Support in Digital Environments, Edited book. Publisher: Cambridge University Press. Editor: Claudia Roda.
- [3] Langendijk EHA, and Bronkhorst AW (2002) Contribution of spectral cues to human sound localization, J. Acoust. Soc. Am. 112; pp. 1583-1596.